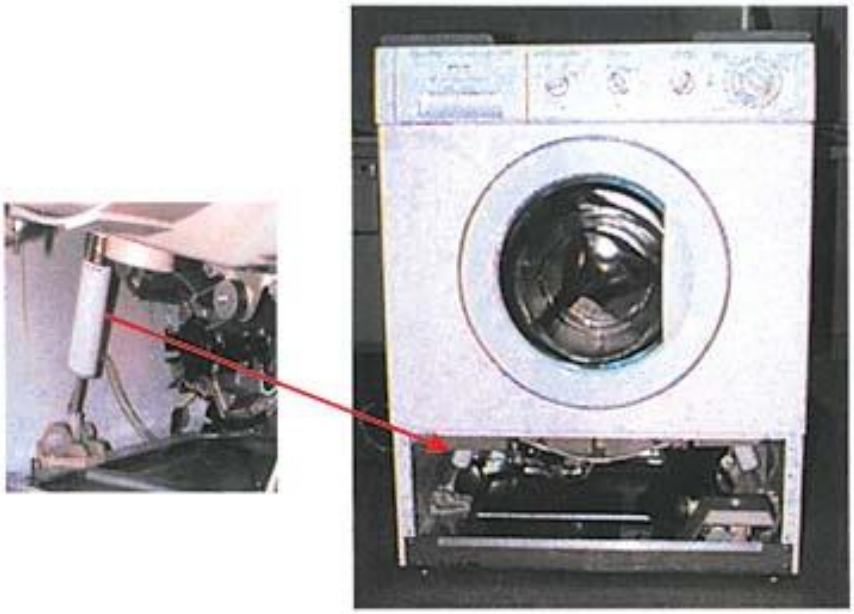
Mekanik för I **(FMEA10) 2020**

Project: Vibration Damping

Project team: _______

Name:	Personal id-number:



Mekanik
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Project: Vibration damping

Project Specification

1. Introduction

In this project we will study the vibrations of a simple mechanical system by using our knowledge in mechanics and the Multi Body Simulation package ADAMS.
We will investigate the motion of a machine-housing due to an internal rotating mass unbalance. The machine housing is mounted on a foundation via an elastic spring system. The motion of the housing creates a force on the foundation. This force is unwanted and we will try to reduce the motion by adding a specific mass-spring-damper system to the machine housing.
The purpose of this project will be to investigate some of the properties of this vibration damping concept.

2. Problem formulation

A machine-housing contains a rotor with a mass unbalance according to Figure 1 below. The unbalance is given by the offset of the centre of mass for the rotor relative to the rotor axle. The rotor is spinning with a constant angular velocity and this produces an acceleration on the housing which is transmitted to the foundation via the supporting spring system. By adding a specific mass-spring-damper system on top of the machine housing the motion of the housing and the forces exerted on the foundation may be reduced. We want to find out how this damping mechanism works and how it could be designed. See Figure 2.

3. Theoretical model

In our theoretical model we assume that the machine housing is a rigid body with mass m_h and with the possibility of a translational motion in the vertical direction

$$x = x(t) \qquad (1)$$

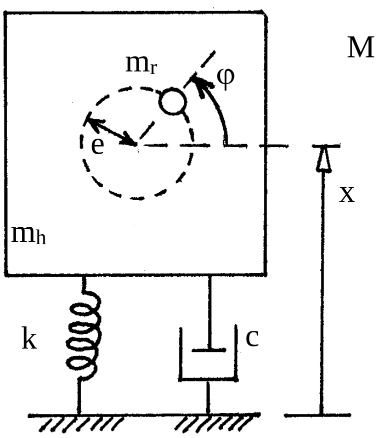
where x is a coordinate measuring the vertical position of the housing relative to the foundation (see Figure 1). The rotor unbalance is modelled as a particle with mass m_r performing a circular motion with radius e and constant angular velocity ω relative to the housing. The total mass of the machine is denoted by m and

$$m = m_h + m_r \qquad (2)$$

The housing is supported by a spring-damper system connected to the foundation (ground). This system is modelled by using a linear spring and linear viscous damper. The force on the housing from the spring-damper system may then be written

$$F = -k(x - x_0) - c\dot{x} \tag{3}$$

where k is the spring constant, x_0 is the position of the housing when the spring is unloaded. and c is the viscous damping coefficient. The machine model is visualized in Figure 1 and will be referred to as the "un-damped machine".



Motion: $\varphi = \omega t + \varphi_0$

Figure 1: Un-damped machine

The damping device ("vibration absorber") mounted on top of the housing is modelled as a particle with mass m_a connected to the housing with a spring-damper system according to Figure 2. The elastic spring constant is denoted κ and the viscous damping coefficient η. If the position of the damping mass relative to the machine housing is given by

$$y = y(t) \tag{4}$$

the damping force D, acting on the housing from the damping device, may be written

$$D = -\kappa(y - y_0) - \eta\dot{y} \tag{5}$$

where y_0 is the position of the absorber mass (relative to the housing) when the spring is unloaded. The machine model is visualized in Figure 2 and will be referred to as the "damped machine".

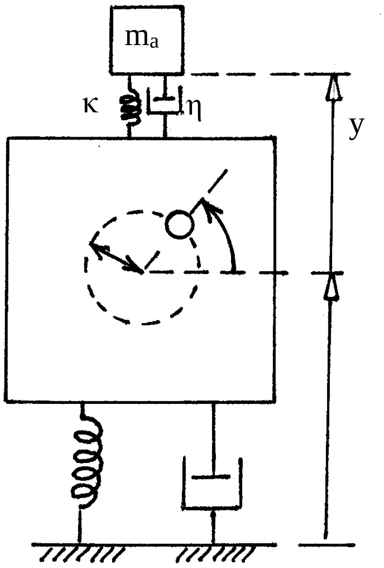


Figure 2: The damped machine.

4. Basic data

The following basic data should be used:

Table 1: Basic data

Parameter	**Symbol**	**Unit**	**Numerical value**
Machine mass	$m = m_h + m_r$	kg	100
Foundation spring constant	k	N/m	-- (Team specific)*
Foundation damping constant	c	Ns/m	3000
Rotor mass	m_r	kg	10
Rotor mass eccentricity	e	m	0.2
Rotor velocity	N	Rpm**	-- (Team specific)*
Absorber mass	m_a	kg	-
Absorber spring constant	κ	N/m	-
Absorber damping constant	η	Ns/m	-

*See **Appendix 2** at the back of this specification. ** Revolutions per minute.

5. Theoretical investigations and damper design

We want to examine the motion of *the un-damped machine* and then design a *vibration absorber* which reduces the motion of the machine housing as much as possible.

The design problem may be formulated as follows:
Choose the mass m_a, the elastic stiffness κ and the viscous damping η of the vibration absorber so that the amplitude of the housing motion becomes as small as possible.
We call this the *“optimal design”*.

5.1 The motion of the un-damped machine

Tasks and questions:

1. Calculate analytically the amplitude of the steady state motion of the un-damped machine housing. Draw a free-body diagram including external forces. Formulate the force equation and solve the obtained differential equation.
   Use data in table 1. Consult chapter 8 in *"DYNAMICS"* and the "*Lecture Notes"* for the theory.
2. Construct a model of the problem using the ADAMS software. Simulate the motion of the machine. Plot a diagram of the vertical position of the machine housing as a function of time. Compare the ADAMS results of the machine housing motion with the analytical solution.
3. Reduce the viscous damping c $(c \to 0)$ of the foundation spring-damper system and observe the motion of the housing. Try to explain what is happening! What is this phenomenon usually called. (Hint: In the simulation choose 'End time' 2, 'Steps' 1000.)

5.2 The motion of the damped machine

The damping mechanism cannot be allowed to be too heavy. We will design a damper with a mass of maximum 10% of the total machine mass, i.e. we have the design restriction:

$$m_a \leq 0.10m \qquad (6)$$

where m is the total machine mass, according to (2).

Tasks and questions:

4. Restore the damping coefficient c to the default value according to Table 1!
5. Construct a model of the damped machine using the ADAMS software.
6. Simulate the motion of the damped machine for different values of mass, stiffness and damping coefficients (m_a, κ and η) of the vibration absorber. Do you find any damping of the housing motion? If not change the values and try again! Compare the amplitudes of the damped machine for different values of absorber mass m_a, absorber spring constant κ and absorber damping constant η. Include plots of these simulations in the report.
7. What mechanical effect may be causing the damping of the housing motion? Try to formulate, in words, a simple explanation (a 'theory')!

5.3 The optimal design

Tasks and questions:

8. Formulate a strategy for the selection of mass and stiffness coefficients (m_a, κ) for the vibration absorber in order to obtain an optimal design.

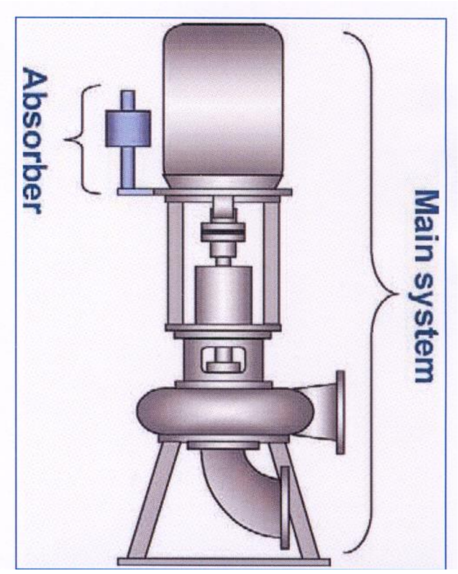
9. Try to find mass, stiffness and damping coefficients (m_a, κ and η) for an optimal design. Use the strategy and your simulation model!

10. Compare the motions of the optimally damped and the un-damped housings by plotting a diagram of the vertical position of the machine housing as a function of time. What is the *amplitude reduction ratio R,* defined by:

$$R = \frac{\text{amplitude of damped machine housing}}{\text{amplitude of undamped machine housing}}$$

11. Can you think of any practical problems with the design of a vibration absorber of this type?

12. Produce a written report on your findings! See **Appendix 3!**



Appendix 1
Short ADAMS manual
for
Project: Vibration Damping

5.1 The motion of the un-damped machine

- **See Computer Exercise 2 ("Datorlabben").**
- If we choose to build a machine housing as a cube with side 100cm then choose the following "Working Grid…"

	X	Y
Size	(2m)	(2m)
Spacing	(10cm)	(10cm)

- Zoom in the entire grid of the working area.

We will not need the gravity in this problem so:

- Select "No Gavity".
- As the machine housing choose for instance "Rigid body: Box". Select Length = Height = Depth = 100cm! Place the box on the "Working Space".
- Change the mass properties of the box!
- Connect the "Box" to "Ground" with a "Translational Spring-damper". Make the "Spring-Damper" as long as possible!
- Use a "Rigid body: Link" (Length = 20cm) to create the eccentricity.
- Connect the "Link" to the "Box". Use a "Joint: Revolute".
- Change the mass properties of the "Link". Set mass = 0.
- Use a "Rigid body: Sphere" to create the rotor mass.
- Connect the "Sphere" to the "Link"
- Change the mass properties of the "Sphere".
- Create a "Rotational Joint Motion" for the "Link+Sphere".
- Create a "Measure" of the y-displacement of the centre of mass of the "Box".
- Test the model by running a simulation. Select an appropriate "End Time" so that "steady state" of the housing motion is obtained. Calculate (by hand) an estimate of the amplitude of the machine housing. Did the model work as expected?

5.2 The motion of the damped machine

- Create the vibration absorber, in the same way as you built the machine housing, and place it on top of the machine housing.
- Assign specific values to the "Design Variables" m_a, κ and η.
- Test the model by running a simulation.

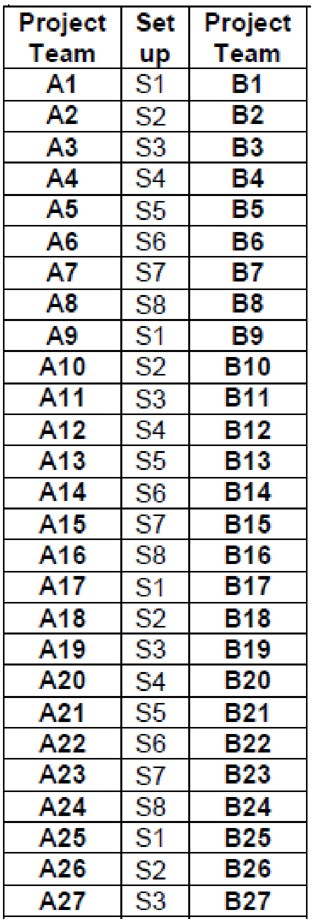
5.3 The optimal design

- How should the mass of the vibration absorber be selected?
- How should the natural frequency of the vibration absorber be designed?

Appendix 2

Team specific parameters

Set up	Spring constant, k (N/m)	Rotor velocity, N (rpm)
S1	8400000	2850
S2	8650000	2900
S3	8700000	2900
S4	8950000	3000
S5	9100000	3000
S6	9200000	3000
S7	9350000	3000
S8	9500000	3000



Project Team	Set up	Project Team
A1	S1	**B1**
A2	S2	**B2**
A3	S3	**B3**
A4	S4	**B4**
A5	S5	**B5**
A6	S6	**B6**
A7	S7	**B7**
A8	S8	**B8**
A9	S1	**B9**
A10	S2	**B10**
A11	S3	**B11**
A12	S4	**B12**
A13	S5	**B13**
A14	S6	**B14**
A15	S7	**B15**
A16	S8	**B16**
A17	S1	**B17**
A18	S2	**B18**
A19	S3	**B19**
A20	S4	**B20**
A21	S5	**B21**
A22	S6	**B22**
A23	S7	**B23**
A24	S8	**B24**
A25	S1	**B25**
A26	S2	**B26**
A27	S3	**B27**
A28	**S4**	**B28**
A29	**S5**	**B29**
A30	**S6**	**B30**

Appendix 3: Anvisningar för skriftlig rapport

Rapport ska skrivas på ett sådant sätt att en kurskamrat som inte har utfört samma projektuppgift har möjlighet att sätta sig in i frågeställningen, utförandet och resultatet för att därefter själv kunna bilda sig en uppfattning om projektuppgiftens utfall. Rapporten kan skrivas på svenska eller engelska. Den skriftliga rapporten ska granskas av en lärare vid avdelningen för Mekanik. För att underlätta diskussion av rapporten ska både ekvationerna och sidorna numreras.

Följande rubriker **skall** ingå i rapporten:

1. The motion of the un-damped machine.
2. The motion of the damped machine.
3. The optimal design.
4. Conclusions and discussion.

Utformningen av rapporten i detalj bestäms av projektgruppen men där skall ingå

Problembeskrivning
Beskrivning av vad uppgiften gick ut på.
Metod
Beskriv kortfattat vilka hjälpmedel som använts vid analysen. Vilka antaganden och vilka approximationer har gjorts? Vilken teori har använts?
Utförande
Berätta hur undersökningen har genomförts. Organisera eventuellt resultatet i tabellform. Diagram ritas med hjälp av dator. Varje diagram ska numreras och förses med beskrivande text. Diagram placeras sist i redogörelsen och refereras till med hjälp av diagramnumret. Inga icke refererade diagram får infogas i rapporten.
Resultat
Ange vilka resultat som erhölls i form av beräknade värden och kvalitativa resultat. Resultatpresentation i form av tabeller och diagram.
Diskussion
Stämmer resultatet med den teori som har antagits? Hur kan eventuella avvikelser förklaras? Finns det skäl att tro att den verkliga problemställningen inte är så idealiserad som teorin förutsätter?